CARBON DISULPHID AS AN INSECTICIDE

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FARMERS' BULLETIN 799

UNITED STATES DEPARTMENT OF AGRICULTURE

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. June, 1917

Additional copies of this bulletin may be obtained free from the
Division of Publications, U. S. Department of Agriculture

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1917

CHEMICALLY pure carbon disulphid is a colorless watery liquid formed by the union of two elementary particles of sulphur with one of carbon. Its chemical symbol is therefore CS_2. The name is spelled in several ways: Disulphid, disulphide, bisulphid, and bisulphide. The colloquial name most frequently used appears to be "high life."

This bulletin gives the necessary facts regarding the nature of carbon disulphid and the general principles involved in the safe, economic, and effective use of this valuable insecticide. It is a revision of Farmers' Bulletin 145, which it replaces, but it includes new information based to a large extent on work conducted by the author at the Alabama Experiment Station and published here with the approval of the director of that station. The bulletin is adapted to all parts of the country.

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INSECT PESTS WHICH MAY BE KILLED BY CARBON DISULPHID.

Carbon disulphid is a liquid which evaporates quickly when exposed to the air, forming a heavy inflammable vapor having great penetrative power so that it is very useful in destroying insect pests. This substance is used most extensively to kill weevils and other pests that injure stored grains, beans, cowpeas, and peas, but it may be employed with advantage to kill many other kinds of insects. These may be arranged in three groups. In one group are species that live underground on the roots of plants or that nest in the ground, as do some aphids, the white grubs, mole crickets, ants, and others; in the second group are species that attack various stored products, such as grain insects, pea weevils, bean weevils, pantry pests of various kinds, and mill insects; and in the third group are species that can not be controlled by the methods commonly employed for their near relatives. In this last group belong certain other insects that can not be combated satisfactorily by spraying and various wood borers that can not be reached with poisons but can be reached easily with vapors.[1]

[1] It should be noted that the degree of infestation does not affect the dosage required.

FORM IN WHICH CARBON DISULPHID IS SOLD AND WHAT IT COSTS.

In small quantities carbon disulphid is put up in tight tin cans; in large quantities (50 to 1,000 pounds), in steel drums. It may be purchased in small quantities from most druggists at from 25 to 35 cents per pound, but if any considerable quantity is to be used it is better to buy from some wholesale druggist, or, better still, directly from the manufacturers. Manufacturers can supply impure grades, which are commonly used for insecticidal work, at a cost of from 10 to 15 cents per pound. The charge for steel drums is paid by the purchaser, but the drums are returnable at purchase price. Addresses of manufacturers may be obtained from any entomologist or from the director of any experiment station.

PROPERTIES OF CARBON DISULPHID.

LIQUID PROPERTIES.

Liquid carbon disulphid is about one-fourth heavier than water. It evaporates very rapidly upon exposure to the air, the rate of evaporation depending largely upon the area of the exposed surface, the temperature of the air and of the liquid, and the height of the wall of the container above the surface of the liquid. Evaporation may be retarded by mixing the liquid with various substances and is almost wholly prevented by covering the surface with water, which, being lighter, floats easily on top just as kerosene floats upon water. The evaporation takes up heat in proportion to its rapidity so that it may produce frost upon a hot day near the evaporation surface. If the liquid is poured upon the hand or anywhere upon the skin a burning sensation will be felt. This is due not to a burning but to a cooling process, as may be perceived readily by touching the spot with the other hand. No injurious effects result from getting it upon the skin, although it takes out the moisture and oil, leaving the skin dry and whitish. If confined on the skin, as under a ring, it causes sharp, burning pain, and this doubtless is similar to the sensation felt by animals when the liquid is poured into the hair, which serves to retard evaporation.

The chemically pure liquid has a sharp taste and a rather sweetish, not unpleasant, odor which is very similar to that of ether or chloroform. The *pure* chemical is completely volatile and will not injure or stain the finest fabrics. It does not affect the edibility of foodstuffs upon which it may be poured, and all trace of the odor disappears quickly upon full and free exposure to the air. The ordinary commercial article, however, has a decidedly yellowish color, due to the excess of sulphur, and a decidedly unpleasant odor, due to the hydrogen sulphid contained in it. *The commercial article, there-*

fore, should not be poured directly upon goods that would show stains or upon food materials, although the vapor from it will not do them harm.

Liquid carbon disulphid is not at all explosive, and there need be no fear in handling it if the cans are perfectly tight. It boils at 115° F., which is about the highest temperature of water in which the hand can be held. One volume of the liquid is said to produce about 375 volumes of the vapor. The liquid weighs a little over 10½ pounds per gallon at ordinary temperatures.

VAPOR PROPERTIES.

The vapor of carbon disulphid is two and sixty-three one-hundredths times as heavy as air, and therefore can be poured from one glass to another, almost like water. The vapor easily can be seen flowing down over the edge of an open vessel containing the liquid. It diffuses rapidly through the air, as can be perceived from the spread of the odor, but as it tends always to work downward rather than upward, the vapor is more dense and has greater killing power at the lower levels. This point has an important bearing upon the application of the material. The vapor appears to have greater penetrative power than does that of any other volatile liquid that has been tested in insecticidal work. This power is far greater than that of hydrocyanic-acid gas, which is another fumigant frequently used. It is possible, therefore, to use carbon disulphid with good results for the treatment of materials which would not be penetrated by other fumigants under natural atmospheric conditions. The expansive tendency is so great that the vapor may exert a pressure of several pounds to the square inch in the container if the temperature of the liquid is increased. The vapor is highly inflammable and explosive when mixed with air in certain proportions.

EFFECTS UPON HUMAN BEINGS OF INHALATION OF VAPOR.

The gas is rated as highly poisonous, producing giddiness, vomiting, congestion, coma, and finally death. These are, of course, its extreme effects. In its ordinary use on a large scale in the fumigation of mills, warehouses, etc., where the worker may be exposed to inhalation of the fumes for some time, only those effects which precede giddiness are likely to be felt. The first appreciable effect is the perception of a very disagreeable odor, but this odor gradually ceases to be noticed, showing that the sense of smell has been deadened. Workmen may even question the fact that they are handling the same material as at the start. The other senses seem to become benumbed simultaneously, so that the operator does not realize that anything is the matter with him. The heart beat becomes more

rapid as the oxygen in the lungs diminishes. The power of thought is very much weakened, and the work is continued in a mechanical way. Hearing and sight are both weakened. But before this weakening process has gone far enough to be really dangerous or injurious the operator probably will feel more or less dizziness. There is no pain or disagreeable sensation, no desire to get away from the vapor, and no sense of suffocation. But when a person has reached this condition it is high time to get into the fresh air.

Owing to the effect of the vapor upon heart action, persons having any trouble or weakness about the heart are cautioned against taking any extended part in the application of disulphid.

It should be understood clearly by those who use it that the action of the vapor is somewhat poisoning as well as suffocating. Should the operator persist in remaining in the room after the dizziness comes on he would be in danger of falling, and, if not discovered, he would soon suffocate. Even if he should get out safely the ill effects would be more marked, and a severe headache, at least, might ensue. If upon the approach of dizziness the operator goes at once to a window, or, better still, out of doors, an abundance of fresh air will remove the ill effects in a few minutes.

The inhalation of the fumes can be retarded somewhat by tying a wet handkerchief tightly over the face. This, however, merely diminishes the amount of air taken into the lungs without affecting the proportion of vapor contained therein. When obliged to enter a room in which there is any considerable amount of the vapor the writer makes use of the following device, which is perfectly effective for a short period. A large paper bag (20 quarts or more) is tied tightly around a short piece of tubing of glass, rubber, or metal inserted into its mouth. When inflated the bag contains sufficient air to enable one to respire into it for several minutes without any discomfort. Being light, it is carried easily by the tube in the mouth so that the hands are left free for any work desired.

PRECAUTIONS TO BE OBSERVED IN HANDLING AND STORING.

The dangers involved in fumigating rooms with carbon disulphid have been discussed rather fully, not because they are very great but in order to lessen the fear that is likely to be great with a material known to involve dangers not fully understood. Danger may be avoided by an intelligent understanding of the precise nature and effects of the chemical. The danger with carbon disulphid is practically of the same nature as that with gasoline, which has come into common use in recent years in many thousands of homes and with hundreds of thousands of automobiles. In reality the danger is less,

since every effort is made to keep carbon disulphid from the presence of fire, while gasoline is used principally in connection with fire. The only peculiar thing about carbon disulphid is that the vapor ignites at a lower temperature than does that of gasoline. It may ignite from any form of fire, or even without the presence of flame, but with a temperature of above 297° F. *There must therefore be no smoking or carrying around of lights where carbon disulphid vapor is strong, and it is hardly safe to have steam pipes very hot, or to turn on or off an electric light or fan. Even the heavy striking of a nail with a hammer might cause an explosion if the necessary density of vapor were present.* Carbon disulphid should not be applied to corn in the bin or to other grain when the mass is known to be in process of heating spontaneously. The disulphid should be stored in a cool, dry outhouse away from fire and where the containers will not rust out and allow the liquid to escape or evaporate. As a further precaution, all containers should be labeled in red, "DANGER—FIRE."

CONFINEMENT OF THE GAS IN FUMIGATION.

Carbon disulphid is applicable only where the vapor can be confined quite closely. The period during which it is necessary to keep the vapor confined varies with the resistant power of the insect species, but in nearly all cases must be for more than 30 minutes, even when a heavy dosage is being used. It is possible for the gas to be confined sufficiently by the soil, the burrow, a tight room or bin, etc., or even by the large volume of a material through which it can only diffuse slowly.

GAS-TIGHT MATERIALS.

Many writers have referred to tightly closed rooms which are plastered or carefully ceiled as being "gas-tight." As a matter of fact, no such room can be made anywhere near gas-tight. Ordinary living rooms, even in well-built houses, are so very far from gas-tight that a large excess of the fumigant is necessary to get anything like satisfactory results in them. It is not strange, therefore, that a wide divergence appears between the results of experiments made by a scientist in some laboratory in glass receptacles which are truly gas-tight and the results of fumigation work under ordinary building conditions, both in the strength of gas required to kill all insects and in the time in which this can be accomplished.

A somewhat extensive testing of materials has shown that ordinary 10-ounce duck, untreated, will transmit practically 85 per cent as much air under a slight pressure as though there were no such

obstacle in the way. All felt materials are extremely porous and are unsatisfactory for use in packing around doors, etc., as they are often used. Heavy, hard-rolled wrapping paper, or 2-ply roofing paper of certain brands, is actually gas-tight and may be used as a lining material between layers of boarding in the construction of fumigation rooms and for pasting over cracks where necessary to tighten a room. Ordinary matched flooring or ceiling alone is very far from being tight.

MAKING A FUMIGATION ROOM OR BIN.

One of the simplest satisfactory containers for fumigation on a small scale is a water-tight barrel. This may be used for the treatment of peas, beans, etc., or for other materials that may be contained therein. The top of the barrel is best closed by spreading heavy wrapping paper, double thickness, over and around the top and tying it tightly.

In making a special room or bin for fumigation work it is best to put on one layer of boards of uniform thickness, flooring or ceiling, and then to cover this with a layer of heavy building paper, tarred paper, or similar material, which is folded or bent to fit into the corners and then is laid so as to overlap 3 or 4 inches and the edges securely pasted or cemented together so as to make it practically one solid piece of gas-tight covering. A final layer of boarding running in an opposite direction to the first is applied to protect the paper from being broken as it is used. Windows should be small and arranged for convenient opening from the outside for ventilation, and door bearings should be against paper surfaces instead of cloth or felt. In such a room or bin fumigation may be practiced with the maximum of efficiency and economy. The application of an ineffective amount of the fumigant is practically a waste of all the material used and often also a waste of the products ineffectively treated.

DIFFUSION OF THE VAPOR.

The vapor diffuses rapidly in the open air, as is evident from the spread of the odor. As has been stated, it must be confined closely in order that a sufficient proportion of it may be maintained in the atmosphere to kill insects, which require far less air, even in proportion to their size, than do higher forms of animals. The vapor naturally tends to spread outward and downward, since it is heavier than air. Consequently when carbon disulphid is applied to a bin of grain or similar material it has been found that the killing proceeds outward and downward from the point of application of the

liquid and forms what may be called a "cone of killing." The apex of the cone is close to the point of application, and the base is against the floor or ground below.

EFFECT OF TEMPERATURE IN FUMIGATION.

An extremely important factor that has been ignored until recently in fumigation work is temperature. The effect of temperature may be judged from the fact that a warm atmosphere will require far more of the carbon disulphid vapor to saturate it than will a cool atmosphere. To saturate 1,000 cubic feet of air at 50° F. requires 53.5 pounds of liquid carbon disulphid; at 59°, 64.6 pounds; at 68°, 77.6 pounds; at 77°, 92.4 pounds; and at 86°, 109.3 pounds. Thus at 86° F., which is a temperature not uncommon, the air will hold more than twice as much disulphid vapor as it will at 50°. Not only is this true, but insects show great differences in vital activities at these varying temperatures. The higher the temperatures, up to a certain point, the greater their activity; and the more active the insects are, the more susceptible to the effects of the gas. In practical work it has been found that it is not advisable to try fumigation with carbon disulphid when the temperature is below 60° F., while the most effective and economical work can be done at the higher air temperatures.

AIDING RAPID VAPORIZATION.

In several ways vaporization may be hastened beyond the rate at which it will occur naturally from the surface of the liquid as it is freely exposed to the air. One common method for use in the treatment of rooms and bins on a small scale is to saturate some absorbent material with the desired amount of liquid and hang it near the top of the room or bin so that the vapor may flow away freely downward and produce quickly the maximum density of vapor. Another method sometimes used in large warehouses is to apply the liquid through a spray pump. The operator using this method must be careful not to stay too long in the gas thus rapidly increasing in density. Where the liquid falls upon wood it is taken up quickly by the wood and is then given off again, but slowly. Spray applications sometimes can be made through holes bored in the ceilings or through the floor of the room above that to be treated, and the spray thus distributed at various points in the room below with no inconvenience to the operator. The holes can be stopped securely except when in use. Still another method, which is a modification of the spray method, is to force the liquid under pressure, mixed with a large amount of air, into the material to be treated so that the gas will have to diffuse throughout the material before it can escape and lose

its killing power. The more quickly the full killing strength of gas can be attained, the more economical and effective the treatment is likely to be. This method is used especially with cotton seed for boll-weevil destruction.

HOW CARBON DISULPHID KILLS.

The way in which carbon disulphid kills has been studied at the Michigan experiment station,[1] where the conclusions have been reached that carbon-disulphid vapor very probably acts upon the fatty tissues in the insect body, dissolving them to some extent; that it tends to coagulate the proteins; and that it prevents the assimilation of oxygen and the carrying on of other processes which are of vital importance to insect life. A certain amount of respiration goes on at all times so long as an insect is alive, but it is evident that respiration will be far less in the egg stage or during the dormant periods in an insect's life than it is in the adult stage and during the periods of its greatest activity. The strength of vapor and the time required to kill, therefore, will vary greatly and accordingly. Similarly, slow-moving insects usually are harder to kill than the quick-moving forms.

TREATMENT FOR INSECTS INFESTING STORED GRAINS, PEAS, ETC.

The most important use for carbon disulphid as an insecticide in the United States is in the fumigation of stored grains, cowpeas, beans, and peas to kill the insects infesting them. Many species of insects are concerned in this inquiry, but all are susceptible to the same treatment. The most important species attacking corn is the so-called black weevil, or rice weevil,[2] which causes a loss amounting to several million dollars annually in each of the South Atlantic and Gulf States. Probably half of this loss could be prevented by certain inexpensive changes in the methods followed in the planting and handling of the corn crop, but for the other half no method of prevention yet tested can equal fumigation with carbon disulphid.

Investigation by the Alabama Experiment Station has shown that the amount of liquid disulphid required for killing grain insects under ordinary conditions of storage is much greater than has been recommended usually, and ranges up to about 20 pounds per 1,000 cubic feet in ordinary rooms where the walls and floor have not been made especially tight, as recommended on pages 12–13.

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[1] Shafer, George D. How contact insecticides kill. *In* Mich. Agr. Col. Exp. Sta. Tech. Bul. 21, p. 18, 1915.

[2] *Calandra oryza* L.

In large masses of corn containing more than 1,000 bushels, where the corn still has the husk on,[1] it is possible to kill enough insects in the interior of the mass to pay for the fumigation, even if the mass is entirely open to the air above and around it. The husks in so large a mass serve to retain the gas long enough to kill weevils, etc., but it would be better in this case to increase the amount of disulphid to 25 or 30 pounds, dividing it into two equal lots and applying one lot at first and then the other after an interval of an hour. The liquid may be poured directly on the grain, as it will not injure it for feeding purposes or in germination. It is hardly possible thus to treat husked, or even shelled, corn without having a tight room or bin in which to do the work.

In fumigating corn in the crib or storage room it is best to level off the corn and then, if the husk is on, to throw out enough ears to leave five shallow holes in quincunx arrangement (i. e., one at each corner of a square and one in the center, thus: ⁙). If the surface area of the stored corn is oblong it may be divided approximately into squares and five holes, arranged as indicated, made in each square. A proportional part of the entire dosage is then poured into each hole and the ears quickly replaced. The room should be closed as tightly as possible, and it may be left closed indefinitely. The best results are obtained by doing this work when the temperature is above 75° F. Fumigation should begin at about 10 or 11 o'clock in the morning, so that the warmer temperature of midday may increase the effectiveness of the gas.

Cowpeas and other leguminous seeds can be stored and fumigated conveniently in water-tight barrels, which are filled with the seed to within a few inches of the top. The dosage needed, about ½ cupful per barrel, may be poured directly upon the peas or into absorbent material packed on top of them. The barrel then should be covered with a double thickness of heavy wrapping paper tied closely and

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[1] HUSK CORN IN THE FIELD.—In the Southern States it has been long the prevailing custom to gather the corn by breaking the ear from the stalk and to store it with the husk on. For several reasons insect injury during storage is generally far greater in the South than it is in the North. Storing corn with the husk on has been supposed to protect it against insect attack in some measure. Recent investigations have shown that this is a mistake in practice. The insect attack begins in the field as soon as the kernels begin to harden and the husk to shrink away from the ear. *Storing with the husk on insures carrying practically every insect from the field to the crib. It practically doubles the volume of storage room required per bushel of corn and also increases greatly the amount of carbon disulphid needed to treat the corn in the crib. Husking the corn in the field, on the other hand, will leave at least three-fourths of the adult insects in the field and thus help greatly in reducing subsequent injury during storage, besides making crib treatment more effective and economical.*

There is no need for an open crib in which to store the thoroughly well-matured corn of the South. Storage rooms may be made tight enough for fumigation and the dosage required for bare ears will be only about 10 pounds per 1,000 cubic feet, or one-half the amount needed with the husk on. Store as soon as the corn is thoroughly matured and fumigate promptly for best results. If insect attack develops in the crib, treat again, using a heavier dosage, or doing the work during warmer weather.

tightly around the top. After a few days the peas should be examined, and if insects are still active they should be treated again, a stronger dosage being given or the work done on a warmer day. The barrels may be kept covered with the paper to prevent reinfestation. The sooner peas are thrashed out and thus treated the better. Treatment should kill immature weevils as well as adults. Other seeds intended for planting can be treated and protected in a similar manner.

TREATMENT OF BUILDINGS.

Agricultural products frequently are brought together in storehouses, mills, etc., in immense quantities, and when allowed to stand for months, as is frequently the case, these materials become particularly favorable places for the nourishment and multiplication of a large variety of insects which can be dealt with only by treating the entire building. It is possible that this fumigation treatment might be objected to by fire-insurance companies as a violation of the policy contract, but there is no record of fire ever having occurred from such treatment of warehouses or mill buildings.

PRELIMINARY INVESTIGATIONS.

When a fumigation of this kind is to be undertaken, a preliminary investigation should be made to determine the nature of the principal pest (or pests), its habits, manner of injury and of breeding, and as much of its life history as may be needed to determine whether one time will be more favorable than another for the treatment. The building or room should be examined thoroughly to determine how it can be made as nearly tight as possible, and its floor area and cubical contents computed. All possible objections to treatment and all dangers involved should then be considered. As a general rule, the advice of a competent entomologist may be obtained free through the State experiment station, and in many cases the entomologist can be secured to take personal charge of the preparation of the building and the application of the treatment.

PREPARATION OF THE BUILDING.

The building should be made as nearly gas tight as is possible and the places into which the insects might crawl for shelter should be eliminated so far as practicable. The pasting of heavy wrapping paper over cracks around the floor edges and around windows, doors, etc., is one of the cheapest and best ways of closing these spaces. Insects sheltered in such cracks may be killed by local treatment. The building should be swept out thoroughly, and a coat of whitewash may be needed sometimes before the treatment is applied. As much as possible of the infested materials should then be exposed to

the strongest action of the vapor. With this in view, materials should be removed from shelves and spread out on the floor. If there are serious objections to allowing the liquid to touch the materials to be treated, it will be necessary to provide a large number of shallow tin pans or plates. The larger these are the better. They should be placed as high in the room as can be done without delaying the application unduly, and care should be taken to see that they are level, although ordinarily no harm will be done if some of the liquid is spilled. No time can be lost in making such adjustments after the application is begun. To reach places which are not accessible by the pan method, it may be possible to use cotton waste or other absorbent material, saturating it with the disulphid and throwing it or hanging it where needed. If the liquid has been purchased in bulk it may be necessary to have several convenient smaller receptacles into which it may be poured so that it can be handled conveniently and rapidly.

MAKING THE EXPOSURE.

As many men should assist in making the exposure as can work to advantage, for the work must be done rapidly. Before the cans or drums are opened every man should receive full instructions as to his division of the work, and cautioned as to the dangers from fire, dizziness, etc. If more than one floor is to be treated, the men should begin at the bottom and work upward on account of the rapid settling of the gas. Every door and window should be closed tightly except that left for escape of the workers. All should begin at the same time, pouring the predetermined amount into each receptacle, and then get out into the open air as quickly as possible. The exit door should then be closed, with paper pasted around it to make it tight, and it should be left closed for 12 hours or longer. The best plan usually is to make the treatment on Saturday afternoon before dark, or on Sunday forenoon, and allow the building to remain locked until early Monday morning. Owners of adjoining premises should be advised regarding the nature of the work, and a watchman may be needed in some cases during the period of treatment.

VENTILATION.

As a matter of fact, most, if not all, of the killing will have occurred during the first 6 hours of the exposure and the building may be ventilated after that time, as a minimum, has elapsed, although it is better to wait 12 hours or longer. In cases of long exposures the vapors will have diffused so fully by the end of 24 hours that there will be no danger to anyone entering the building to open it for ventilation. If, however, it is found that the gas is still very strong, the respiration bag, as described on page 6, should be used. The

odor disappears rapidly where the air is moving at all. Traces of it may linger in close or damp corners for some time, but there is no danger from fire or to health from slight amounts of vapor.

FUMIGATION OF SACKED COTTON SEED.

On account of its fuzzy nature and the immense number of small air spaces formed in tightly packed masses of cotton seed, this material has proved to be a difficult subject for fumigation. Hydrocyanic-acid gas does not penetrate more than a few inches into cotton seed, which carbon-disulphid vapor can penetrate for several feet downward from the point of application of the liquid, but the penetration by its own force is slow and the loss of time is unnecessary. A method of forcing specified quantities of the liquid and its vapor into the interior of the mass of cotton seed, or into sacks of seed, has been devised and described.[1] By this method a squad of four men can treat 600 or more sacks of seed a day. A charge of 1 ounce of disulphid is used for each sack of seed containing about 3 bushels, and the liquid and its vapor are driven into and diffused through the seed by pressure of air obtained from a small air pump. The cost for liquid used amounts to less than one-third of a cent per bushel, and the expense for the treatment, including labor, will be about one-half cent per bushel. This method of application can be used with many other subjects to good advantage. The liquid and vapor are released in the interior of the mass to be treated, thus confining all the vapor and forcing it to diffuse throughout the material before it can escape and lose its killing power.

DESTRUCTION OF ANTS.

Carbon disulphid is the best remedy known for the destruction of colonies of ants, which frequently become great nuisances to householders, farmers, and gardeners. With a little careful observation most of these ants, except possibly the little red house ant, can be traced to their outdoor homes. It helps little to destroy even a large number of the workers, as the supply will be renewed quickly through the rapid breeding of the colony. The only really effective way of stopping the annoyance or injury is to destroy the queens which lay the eggs and rarely leave the nests.

In work with the Argentine ant in Louisiana[2] it was found that the colonies could be localized during the winter season or in very wet

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[1] Hinds, W. E. Fumigation method for sacked cotton seed. *In* Jour. Econ. Ent., v. 8, no. 4, p. 400–402, pl. 21. 1915.

Hunter, W. D. The boll-weevil problem, with special reference to means of reducing damage. U. S. Dept. Agr. Farmers' Bul. 512, p. 37–39, fig. 9. 1912.

[2] Newell, Wilmon. Measures suggested against the Argentine ant as a household pest. *In* Jour. Econ. Ent., v. 2, no. 5, p. 324–332. 1909.

situations by furnishing warm places for the nesting of the ants. For the winter, trap boxes 2 by 2 by 3 feet in size were filled with leaves, cotton seed and straw or other porous material. These were placed in the open about the 1st of October, so that the contents might be wet by the rains and then become warm through the process of decay. This material proved so attractive to the ants that practically all colonies within a radius of 30 or 40 yards would take up their abode in it as cool weather came on. In a single trap of this kind it was estimated that more than 1,000 fertile queens were present. In midwinter the cracks in the box were closed tightly, the top covered with a waterproof canvas, and carbon disulphid applied, so that all ants were destroyed at once. This appears to be one of the most economical and effective methods for controlling the Argentine ant.

In the destruction of colonies of the agricultural ants which are very common in the southwestern States carbon disulphid treatment has given most satisfactory results.[1] The liquid is evaporated under an airtight, galvanized-iron tub, which is inverted over the entrances to the colony. The fumigation is begun when the gateways to the nest are open, thus permitting the vapor to flow into the tunnels and penetrate to the lowest chambers in the nest. If other openings occur that can not be covered with the tub at one time, they should all be closed by piling dirt around the tub. One to three ounces of liquid should be used, depending upon the apparent size of the nest, and the tub allowed to stand for five or six hours. By this time all ants will have been killed, and the tubs may be moved to other colonies.

Where ants infest the surface soil generally throughout a considerable area, holes not more than 18 inches apart and several inches deep may be made with a stick or iron bar, an ounce of disulphid poured into each, and the holes closed immediately. After the whole area has been treated the ground should be wet thoroughly or covered with waterproofed canvas, or paper, or wet blankets, to aid in confining the gas.

USE OF CARBON DISULPHID AGAINST WHITE GRUBS AND MOLE CRICKETS.

White grubs, which are the young of the so-called May beetles or June beetles, occur throughout the United States and frequently are so abundant as to demand treatment. Their period of development is long, extending over two or three years, and during this period they are feeding upon the roots of plants. Mole crickets are most abundant in the Southern States and in the islands in the Gulf of Mexico, and they produce a full generation each year. Both of these

[1] Headlee, T. J., and Dean, Geo. A. The mound-building prairie ant. Kans. Agr. Col. Exp. Sta. Bul. 154, p. 178–180. 1908.

common pests in gardens and lawns may be destroyed by the method recommended for use against ants infesting the soil. For best results the soil should be fairly permeable and at least 8 inches in depth.

TREATMENT FOR APHIDS LIVING UNDERGROUND.

The first extensive use of carbon disulphid as an insecticide was against the grape Phylloxera in France. The Phylloxera is a species of aphis which lives upon the roots of the vine. It is native to America but was introduced by accident into France about 1859, where for a time it threatened to destroy the grape-growing industry. By 1863 more than 200,000 acres of vines were being treated annually with carbon disulphid for this pest. The following paragraphs give a brief summary of the principal conclusions reached by French workers in their fight against the Phylloxera. They are included here because they have a general application to all fumigation for underground insects.

DIFFUSION OF THE VAPOR IN THE SOIL.

The liquid evaporates in the soil as it does in the air, only much more slowly. The vapor diffuses through the air spaces of the soil, producing an atmosphere that may be fatal to all insects reached by it. The rate of evaporation, extent of diffusion, and persistence of the vapor in the soil vary widely in soils of varying character and condition. It becomes necessary, therefore, to vary the rules for application according to the influence of these factors to secure the destruction of all insects without injury to the plants.

EFFECT OF SOIL MOISTURE.

Carbon disulphid evaporates most rapidly in a warm, dry, sandy soil, and the persistence of the vapor is shortest in such soil. In fact, in such soil the diffusion is so rapid that most insects will survive an ordinary treatment, and if the dose is increased greatly to kill the insects there is grave danger of killing the plants also. Treatment can not be applied successfully in such soil unless the surface soil can be wet or covered after the treatment. On the other hand, diffusion is slowest in very heavy, wet, clay soils, and when the soil is saturated with water the evaporation is almost entirely prevented. Moisture lowers the temperature and decreases the permeability of the soil; it also prevents evaporation and retards diffusion. Between these two extremes there is a medium character and condition of the soil which is most favorable for the treatment.

EFFECT OF CHARACTER OF THE SOIL.

Sandy soils permit an even but too rapid diffusion and loss of vapor. Rocky soils are not of even texture, and naturally the vapor follows the line of least resistance. Heavy clay soils, when very dry, are usually much broken by cracks and fissures which may run from the surface to a considerable depth and permit the gas to escape without permeating the soil to any considerable extent. When such soil is moderately moistened it is even in texture and favorable to treatment.

DEPTH OF SOIL.

The depth of the soil is an important factor in determining how much disulphid should be used for a given area. If surface soil is very shallow and the subsoil very dense and impervious, it is evident that much less liquid will be required to produce a killing atmosphere than will be needed in soil of much greater depth. The amount of liquid used should be proportional to the permeable depth of the soil. In heavy, compact soils increase the number of injections and diminish the dose in each; in light, deep, permeable soils decrease the number of holes and increase the dose in each.

AMOUNTS TO USE.

Grapevines growing in medium fine, moderately moist soils were uninjured by doses of from 1 to 1½ ounces in each of three holes made at about 16 inches from the base of the vine and at a depth of about 20 inches, while 2½ ounces to a hole proved fatal to them.

REPEATED TREATMENTS.

Best results are obtained by dividing the amount of liquid to be applied and giving two applications of the half dose, separating the applications by from 6 to 10 days. The holes made for the second treatment are then placed intermediately between those used for the first. The depth of holes may range from 12 to 16 inches. Spring is the most favorable season for treatments.

TREATMENT FOR ROOT-MAGGOTS.

Carbon disulphid has been used with varying degrees of success for the cabbage root-maggot since 1880. Its efficacy varies considerably with the nature of the soil, and many of the failures reported have been due very largely to improper or too tardy application. If the liquid comes into direct contact with the roots of the young plants, it is sure to prove fatal, but a considerable proportion of the vapor will do no harm. If treatment is delayed until after the plants have wilted, it is very likely that they will not recover, even though the enemy may be killed, but the death of such plants in such cases can not be attributed fairly to the disulphid treatment. Many

growers who have tested it thoroughly claim that it will work in either clay or sandy soil, and that it destroys both maggots and pupæ. In applying the disulphid for root-maggots the dose is distributed in one or two holes made not nearer than about 4 inches from the base of the plant and running down to a point a little below the roots. The holes must be closed tightly with earth and compacted by pressure with the foot. The dose varies from 1 teaspoonful for each small plant to a tablespoonful for large plants.[1] One injection should be sufficient if made in time, but if delayed too long nothing can save the plants.

TREATMENT FOR APHIDS ON LOW-GROWING PLANTS.

Aphids frequently become extremely abundant upon melon, citron, and other cucurbit vines and upon young cabbage plants, etc. Here they are very hard to control by spraying with contact insecticides because of the curling of the leaves. Carbon disulphid has been used successfully for the control of melon aphids by evaporating the liquid under a tub which covers the vines. Another form of covering used for the plants is a box made of a light frame of wood about 24 inches square by 8 inches high, covered with closely woven muslin cloth which is soaked with linseed oil and then dried to make it gas-tight. The cloth is made to project some 6 or 8 inches beyond the frame so as to form a loose flap around the outside upon which dirt can be piled to make the covering fit tightly to the ground. These boxes are light, durable, and convenient to handle.

The dose consists of 1 teaspoonful (1 dram) of liquid to a plant, or for a box containing about 1 cubic foot, and should be increased proportionately with larger boxes. If the receptacle is of irregular shape, but water-tight, the contents may be determined very accurately by filling it with water. It takes very nearly 7½ gallons (30 quarts) of water to fill 1 cubic foot of space.

The liquid may be evaporated from a shallow dish, or arrangement may be made so that the liquid can be poured through a large hole in the top of the box into some absorbent material fastened permanently beneath it, and the hole then closed tightly with a stopper. On account of the small space that is being treated, special care should be taken to measure the amount of liquid accurately. The covers should remain in place for one hour and then be moved to fresh plants. With from 50 to 100 boxes, a field may be treated with comparative rapidity, and the vapor will reach the aphids much more thoroughly than if applied in any other way. Plants will be more resistant to the vapor at night, when the breathing pores (stomata) are closed.

[1] Four teaspoonfuls are approximately 1 tablespoonful, and 2 tablespoonfuls are approximately 1 fluid ounce.

DESTROYING WOOD-BORERS.

Much has been written concerning the use of carbon disulphid to destroy borers in wood. It is evident that only the larger borers which work in the trunks and larger branches of valuable shade and fruit trees will be good subjects for this work. Usually there are few of these large borers in a trunk, and the outlets to their burrows are marked by the "saw-dust" and castings which they throw out from them. In attempting this treatment, first close all burrows with a clay plug and after a day or two re-examine them to see what burrows are really occupied. Clean-cut, empty holes in the trunk are likely to be only the exit holes from which insects have emerged, so it would be a waste of time and materials to treat such cavities.

METHOD OF TREATMENT.

Having cleaned out the mouth of the hole as well and deeply as possible, roll a small wad of cotton on a toothpick, wet it with disulphid, push it into the cavity as far as possible, and immediately close the hole tightly with putty or, better, with grafting wax. Only a drop or two of liquid is likely to be needed and it should not be applied so as to run down into the burrow as a liquid. The vapor should penetrate to the farthest part of the cavity and destroy any stage of the borer that may be present.

A similar method has been used very successfully by the writer in destroying borers that were working in a piano. No treated burrow was ever opened.

TREATMENT FOR CLOTHES MOTHS AND FOR OTHER HOUSEHOLD INSECTS.

The various insects which commonly infest woolens, felts, furs, etc., often can be conveniently and surely destroyed by carbon disulphid, which will destroy all stages of the pests that may be present. In keeping woolens, felts, and furs, therefore, it is good practice to place them in a whole cotton bag (pillow case), tying it up tightly, and then store in a tight paper-lined trunk, a large packing box, or some such receptacle. (A water-tight barrel will do well.) When all are stored apply the disulphid, putting one-half cupful of the liquid into a shallow dish to evaporate or pouring it directly upon the materials if staining will not injure them. Newspapers or wrapping paper then should be spread over the top and the receptacle closed tightly. If the box is really tight there will be no further trouble, but to be on the safe side it is well to repeat the treatment once or twice during the summer. The odor disappears quickly when the articles are hung out in the open air again.

It is a good plan to provide for this treatment, which is needed in every home, by having an especially large, gas-tight and insect-tight packing chest with a very closely fitting cover. A hole should be bored through the cover and a small sponge, bunch of cotton waste, or similar absorbent material fastened below the opening on the inside. The chest may then be kept tightly closed and the carbon disulphid applied by pouring it through the opening, which thereupon is closed with a cork. The small cost of such an arrangement will soon be balanced by the convenience and security of the protection afforded. Carpets, rugs, blankets, woolen clothing, furs, etc., can be rid surely of all insect pests by inclosure for a few days in such a box. The dose used should be at the rate of at least 10 pounds to 1,000 cubic feet.

Among the numerous insects found in houses there are few that may not be reached successfully with carbon disulphid applied as directed for the fumigation of buildings. (See pp. 12–14.) Cockroaches, croton bugs, bedbugs, fleas, carpet beetles, etc., all can be destroyed by proper use of this liquid. The holds of large ships frequently are cleared of such pests, and also of rodents, in this manner.

DESTROYING MUSEUM PESTS.

Carbon disulphid is used very generally for the destruction of a number of insect pests which ruin museum specimens. Such specimens usually are inclosed in fairly tight showcases, trays, or boxes, and these can be treated rapidly and successfully simply by inserting the necessary amount of liquid and then closing doors or covers normally. In this way many museums are treated regularly as a measure of precaution, even though no pest is known to be present. Sometimes specimen trays or materials are placed in especially constructed, tight rooms or chests within which one general treatment reaches all of the contents. With this method care must be taken to see that boxes and trays are opened so that the vapor can diffuse through all of them.

SPECIES FACTOR IN INSECT RESISTANCE TO CARBON DISULPHID.

Great variation has been found in the resistance of different species of insects to carbon disulphid fumigation. This may be spoken of as the species factor and should always be considered in such work. Just as in the case of ordinary insect-killing bottles in which sodium cyanid is now used, the bumblebee probably is the easiest insect to kill with carbon disulphid. In a saturated atmosphere of disulphid at about 90° F. a bumblebee will die in a few seconds, while under

the same conditions the cowpea weevil[1] will live for about 35 minutes, the rice weevil[2] for about 60 minutes, and the saw-toothed grain beetle[3] for about 120 minutes.

EFFECT OF CARBON-DISULPHID FUMIGATION UPON THE GERMINATION OF SEEDS.

It would appear from numerous tests that there is practically no danger of injuring germination in treating seeds that are well matured and dried out before treatment is given. *It would not be wise to treat moist seeds, or planting seed of any kind, during periods of very humid atmosphere*, as the seeds might take up enough moisture to make them liable to injury from the vapor.

SUBSTITUTES FOR CARBON DISULPHID IN FUMIGATION WORK.

A number of other volatile materials have been tested more or less carefully in the search for a fumigant that would be as effective as carbon disulphid and safer to handle on account of having nonexplosive qualities. Among this number carbon tetrachlorid is probably of largest value, but even with this material it is necessary to use several times as much as is required of carbon disulphid, and the fumigation to be effective is several times as expensive. It does not appear probable that any of these substitutes is likely to come into general use.

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[1] *Pachymerus chinensis* L. [2] *Calandra oryza* L. [3] *Silvanus surinamensis* L.

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